

SUBSTITUTE SPECIFICATION

DESCRIPTION

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RFID TAG DEVICE

TECHNICAL FIELD

[0001] The present invention relates to RFID tag devices  
and position detection and communication methods using  
10 the same, and specifically to an RFID tag device based  
on passive modulation, but capable of performing, for  
example, QPSK modulation for wireless communication by  
using a loop antenna or a dipole antenna, and position  
detection and communication methods using the same.

15

BACKGROUND ART

[0002] Patent Document 1: Japanese Laid-Open Patent  
Publication No. 10-224262

[0003] (Tags for radio frequency identification  
20 communication systems)

RFID is wireless equipment for identifying mobile  
objects, which is attached to or held by a commodity, a  
person, a car, a road sign, etc., and in response to a  
radio wave from an interrogator (a reader/writer),  
25 notifies individual information and position information  
to the interrogator.

[0004] The RFID is considered not only as an alternative

to the barcode, but also as elemental technology for implementing an entirely new infrastructure for a future network community. The research and development of RFID currently underway mainly concentrates on communication  
5 within a relatively short range of several tens of centimeters, but if it is possible to realize low-cost small RFID tags capable of communication from relatively afar, such as from about 10 meters away, the application range will be conceivably further extended.

10 [0005] When such is attached to a commodity, a person, a car or a road sign, for example, its individual information and position information are read by a mobile object from 10 m away, making it possible to readily enjoy safety and convenience.

15 [0006] The above Patent Document 1 describes a conventional passive RFID tag device. According to this, the conventional passive RFID tag device is basically configured as shown in FIG. 1, and therefore has a problem that its possible communication range is short  
20 for the following reasons.

(1) A response signal is created by frequently changing impedance  $Z_v$  between antenna feeding points (1) and (2) to repeat reflection and absorption of incident radio waves, so that the transmission output (conversion  
25 efficiency) is low, and the load impedance  $Z_v$  is applied between the feeding points (1) and (2), resulting in considerable loss of received power.

(2) The source voltage for a control circuit is created by directly diode-rectifying an RF signal received between the antenna feeding points (1) and (2), and therefore the output voltage is low.

5 (3) ASK or BPSK is used as a subcarrier modulation method, and therefore the amount of information that can be transmitted per transmission power is small.

#### DISCLOSURE OF INVENTION

##### 10 PROBLEM TO BE SOLVED BY THE INVENTION

[0007] The present invention aims to overcome the drawback with the above conventional technology by the configuration shown in FIG. 2, and expand the communication range to several times or more that in the  
15 conventional method.

##### MEANS FOR SOLVING PROBLEM

[0008] The main points of the present invention for solving the above problems are as shown below.

20 [0009] The conventional method is based on equilibrium feeding/equilibrium system modulation (a two-terminal circuit for antenna operation), whereas a method of the present invention is based on disequilibrium feeding/equilibrium system modulation (a three-terminal  
25 circuit for antenna operation). The conventional method is based on simple rectification of received RF signals, whereas the present invention employs a circuit based on

a combination of a stub resonance-based, impedance transformation boosting scheme and a ladder boosting scheme. The conventional method is based on ASK or BPSK modulation, whereas the present invention is based on  
5 passive modulation, but can employ a QPSK modulation circuit. The equilibrium feeding means balanced feeding, the disequilibrium feeding means unbalanced feeding, and the equilibrium system modulation means an impedance modulation system of balanced load.

10 [0010] Specifically, an RFID tag device of the present invention includes a divided microstrip antenna having a GND plate 5 (a ground plane conductor), a power receiving circuit based on a combination of a stub resonance-based, impedance transformation RF boosting  
15 scheme and a ladder boosting/rectifying scheme, and a local oscillator circuit for generating a response subcarrier signal, and a dividing position (3)-(4) of the divided microstrip antenna is slightly deviated from a longitudinal center point across strip conductors. In  
20 the present invention, a passive QPSK modulation scheme can be used as a modulation method.

[0011] Also, according to the RFID tag device of the present invention, it is preferred that impedance modulation elements  $Z_v$  of the divided microstrip antenna  
25 are respectively connected to opposite ends of strip conductors 3 and 4 in the width direction so as to connect divided conductors. The impedance modulation

elements  $Z_v$  constitute an equilibrium system modulation circuit.

The impedance modulation elements are preferably PIN diodes or varactor diodes. Also, a voltage or current  
5 controlled three-terminal element using a transistor, rather than a diode, is preferable.

[0012] Further, according to the RFID tag device of the present invention, an extremely small capacitance (1 pF/GHz or less) is preferably used for connecting the  
10 power receiving circuit and an antenna feeding point (3) to perform high-impedance capacitive feeding. As a result, disequilibrium feeding is performed. Note that in order to maximize the receiving efficiency of the antenna, the antenna feeding point (3) may be positioned  
15 so as not to correspond to a dividing point of the divided microstrip antenna.

[0013] Also, according to the RFID tag device of the present invention, it is preferred that capacitive load impedances in a stub resonator and a ladder boost  
20 rectifier circuit of the power receiving circuit are parallel resonant, and further, the capacitive feeding impedance are series resonant.

[0014] Further, according to the RFID tag device of the present invention, it is preferred that when considering  
25 longitudinal connections of capacitors in the ladder boost rectifier circuit of the power receiving circuit as GND- and receiving-side rails, capacitor capacitance

of the receiving-side rail is smaller than that of the GND-side rail, a first diode between GND and a receiving point is eliminated, and a high-frequency and high-impedance input is receivable by a DC short.

5 [0015] Also, according to the RFID tag device of the present invention, a logic circuit including a  $1/4$  frequency divider, a shift register and a data selector is preferably used in the passive QPSK modulation method, and MPSK modulation is preferably applied by using a  $1/M$   
10 frequency divider, an M-stage shift register and an M-input data selector.

[0016] Further, according to the RFID tag device of the present invention, information is preferably recorded to a memory in units of two bits in accordance with the  
15 passive QPSK modulation method.

[0017] Also, the RFID tag device of the present invention preferably includes an timing generator circuit for obtaining an output enable signal in the passive QPSK modulation method, and the output timing generator  
20 circuit preferably generates a train of pulses with a random delay time having a fixed width and a fixed frame cycle, based on a source voltage size and a clock signal.

[0018] According to the RFID tag device of the present invention, it is preferred that by using a transducer  
25 such as a temperature sensor quartz resonator as the local oscillator circuit for generating the response subcarrier signal, a sensor function capable of allowing

its oscillating frequency to be read by an external unit is additionally used.

According to a position detecting method for a mobile object having no RFID tag of the present invention, in a system composed of the RFID device and one or more master devices (interrogators), whether or not an obstacle is present in a radio wave propagation path extending between each RFID tag device and each interrogator is determined based on the presence or absence of communication between the RFID tag and the interrogator.

[0019] In the position detecting method for a mobile object having no RFID tag, a plurality of radio wave propagation paths present between each RFID tag and each interrogator are preferably distinguished based on a combination of a local oscillating frequency for generating a response subcarrier of each RFID tag, a response timing and a frequency of an interrogation radio wave outputted from the interrogator and timing of generating the interrogation radio wave.

According to a position detecting method for a mobile object having an RFID tag of the present invention, radio waves at two or more frequencies are transmitted to an RFID tag device from an interrogator having two or more antennas dedicated for reception or used for transmission and reception, and based on a difference in delay time obtained from a difference in phase between

receiving antennas in a signal for response thereto, maximum likelihood determination of a position of the RFID tag is performed.

[0020] According to the position detecting method for a mobile object having an RFID tag, in the case where in order to enable a three-dimensional RFID tag position determination, an interrogation device having four or more antennas dedicated for reception or used for transmission and reception is used, it is preferred to eliminate a commonly measured distance offset by obtaining a group delay time in each radio wave propagation path based on four or more sets of frequency responses measured for the two or more frequencies, and obtaining a difference in delay time with reference to at least one of the sets.

It is preferred that the RFID tag device of the present invention includes two or more tag antennas in order to expand its possible communication range.

[0021] According to a communication method of the present invention, the RFID tag device periodically changes directionality of an intense response subcarrier radio wave, which is synthesized by periodically changing a phase of a local oscillating signal provided to each tag antenna for generating a response subcarrier signal, thereby returning an intense response radio wave toward an interrogator in a wide area.



#### EFFECT OF THE INVENTION

[0022] By employing these configurations, it is made possible to achieve considerable effects as below.

[0023] Disequilibrium feeding and equilibrium system  
5 modulation (a three-terminal circuit for antenna operation) are employed, and therefore it is possible to achieve the effect of maximizing the reception efficiency of an antenna.

[0024] Also, by employing a circuit based on a  
10 combination of a stub resonance-based, impedance transformation boosting scheme and a ladder boosting scheme, it is possible to obtain a reception voltage of five times or more that of conventional schemes.

[0025] Further, by employing a QPSK modulation circuit,  
15 but based on passive modulation, it is made possible to transmit information in an amount twice that of the conventional method per unit of transmitting power.

#### BRIEF DESCRIPTION OF DRAWINGS

20 [0026] FIG. 1 is a schematic diagram illustrating a conventional RFID tag device;

FIG. 2 is a schematic diagram illustrating an RFID tag device of the present invention;

FIG. 3 is a perspective view illustrating Example 1 of  
25 the present invention;

FIG. 4 is a top view illustrating a control circuit chip according to Example 1 of the present invention;

FIG. 5 is an equivalent circuit diagram illustrating an example of a boosting/rectification operation of the present invention;

FIG. 6 is a diagram illustrating Example 2 of the  
5 present invention;

FIG. 7 is a diagram illustrating Example 3 of the present invention;

FIG. 8 is a diagram illustrating Example 4 of the present invention;

10 FIG. 9 is a diagram illustrating Example 4 of the present invention;

FIG. 10 is a graph showing a frequency response of a 10-stage Cockcroft-Walton circuit with a -3 dBm input, which uses HRU0302A ( $C_0 = 70$  pF) as diodes;

15 FIG. 11 is a graph showing a frequency response of a 10-stage Cockcroft-Walton circuit with a -3 dBm input, which uses HSB226 ( $C_0 = 2.4$  pF) as diodes;

FIG. 12 is a diagram showing a batch reading method for a plurality of RFIDs, wherein  $t_{mn}$  of each RFID is  
20 determined by generating random numbers, a carrier signal from a master device (an interrogator) is modulated, and returned in packets with an ID code being carried thereon; note that the master device is prepared for the case of single reading of a return signal from  
25 each RFID by using a semi-synchronous delay detection system (packets cannot be demultiplexed at the same time), and the case of double reading by using a carrier

phase split synchronous detection system (two packets can be demultiplexed at the same time);

FIG. 13 is a graph showing a simulation result for an average completion time of reading in the case where the number of RFIDs and a packet duration are changed in a batch reading method for a plurality of RFIDs that performs packet transmission at random time within a 1-second frame;

FIG. 14 is a diagram illustrating a planar antenna structure for RFID according to the present invention and a model for computer simulation; note that a spectrum analyzer in the diagram reads a received signal level of  $f_0 + f_{L0}$ ;

FIG. 15 is a graph showing a frequency spectrum of response reception signals from RFIDs, which is measured by using HP83620A (Synthesized Sweeper);

FIG. 16 is a graph showing a result of comparing between the conventional art (dipole) and the present invention (microstrip) with respect to the level of a response reception signal from an RFID at a distance  $z = 5\lambda$  when a  $\lambda/2$  dipole is used as a transmitting/receiving antenna of an interrogator;

FIG. 17 a graph showing a frequency response of a stub resonance boost rectifier circuit of the present invention in the case where an RF input is -10 dBm and a DC load resistance is  $R_L = 33 \text{ k}\Omega$ ;

FIG. 18 is a graph for a comparison of frequency

characteristics of gain with respect to a response  
reception signal from an RFID when the distance between  
an interrogator and the RFID is  $z = 5\lambda$ , by changing a  
height  $h$  between a microstrip line and GND; note that  
5 the length  $L = 0.36\lambda$  and width  $w = 0.0525\lambda$  of the  
microstrip line, and the equivalent series resistance  $R$   
 $= 0\Omega$  and equivalent junction capacitance  $C_0 = 1$  pF of a  
PIN diode are fixed;

FIG. 19 is a graph for a comparison of frequency  
10 characteristics of the gain of a response reception  
signal from an RFID when the distance between an  
interrogator and the RFID is  $z = 5\lambda$ , by changing the  
width  $w$  of a microstrip line; note that the length  $L =$   
 $0.36\lambda$  and height  $h = 0.021\lambda$  of the microstrip line, and  
15 the equivalent series resistance  $R = 0\Omega$  and equivalent  
junction capacitance  $C_0 = 1$  pF of a PIN diode are fixed;

FIG. 20 is a graph for a comparison of frequency  
characteristics of gain with respect to two types of  
response reception signals Low-f and High-f from an RFID  
20 when the distance between an interrogator and the RFID  
is  $z = 5\lambda$ , by changing the equivalent series resistance  
 $R$  of a PIN diode in case of a short circuit; note that  
the equivalent junction capacitance  $C_0 = 1$  pF of the PIN  
diode in case of an open circuit is fixed; also the  
25 length  $L = 0.36\lambda$  of the microstrip line is fixed, and  
the height and width thereof are respectively  $h = 0.014\lambda$   
and  $w = 0.0525\lambda$  in the case of Low-f and  $h = 0.028\lambda$  and

w =  $0.035\lambda$  in the case of High-f;

FIG. 21 is a graph for a comparison of frequency characteristics of the gain of a response reception signal from an RFID with respect to the maximum value when the distance between an interrogator and the RFID is  $z = 5\lambda$ , by changing the equivalent series resistance and equivalent junction capacitance of a PIN diode;

FIG. 22 is a diagram according to Example 3 of the present invention, showing a method for estimating a three-dimensional location of an RFID based on a difference in reception phase of a response signal from the RFID, which is obtained by a master device (an interrogator) transmitting an FMCW carrier signal; note that synchronous detection of  $\omega_n + \Delta$  is performed for each signal received by antennas of the master device, the three-dimensional location is estimated based on at least three parameters in the equation of the diagram; in this case, a reflected wave is also received by the estimation device, and therefore a time-delay measurement technique based on the MUSIC algorithm or the like is used for a response signal even if it is of a multi-frequency type;

FIG. 23 is a graph showing a simulation result of estimating a three-dimensional location of an RFID according to Example 3 of the present invention, which is obtained as an average in 100 rounds with respect to RMS positional error; note that the RFID is positioned

at random within a range of  $6\text{ m} \times 6\text{ m} \times 6\text{ m}$ , and spacing between receiving antennas of an interrogator is 50 cm;

FIG. 24 is a diagram according to Example 4 of the present invention, showing the case of expanding a  
5 communication range for in-phase modulation by forming an array of RFID microstrip elements; note that a spectrum analyzer in the diagram reads a received signal level of  $f_0 + f_{L0}$ ;

FIG. 25 is a graph of an analysis result of the  
10 directionality of sensitivity for receiving a response from the RFID shown in FIG. 24 according to Example 4 of the present invention in the case where a dipole is used as a transmitting and receiving antenna of an interrogator at a distance of  $z = 20\lambda$ ; the microstrip  
15 element is configured such that  $L = 0.36\lambda$ ,  $w = 0.0525\lambda$  and  $h = 0.02\lambda$ , and this figure was compared between the case where only one element is used and the cases where three elements are used with the different spacing of the elements;

20 FIG. 26 is a diagram according to Example 4 of the present invention, showing the case of expanding a communication range for reversed-phase modulation by forming an array of RFID microstrip elements; note that a spectrum analyzer in the diagram reads a received  
25 signal level of  $f_0 + f_{L0}$ ;

FIG. 27 is a graph of an analysis result of the directionality of sensitivity for receiving a response

from the RFID shown in FIG. 26 according to Example 4 of the present invention in the case where a dipole is used as a transmitting and receiving antenna of an interrogator at a distance of  $z = 20\lambda$ ; the microstrip element is configured such that  $L = 0.36\lambda$ ,  $w = 0.0525\lambda$ ,  $h = 0.02\lambda$ , and three elements are spacing of  $0.7\lambda$ , and this figure was compared between the case where the center element is operated in the in-phase modulation mode and the case where the center element is operated in the reversed-phase modulation mode;

FIG. 28 is a graph of an analysis result of the directionality of sensitivity for receiving a response from the RFID shown in FIG. 26 according to Example 4 of the present invention in the case where a dipole is used as a transmitting and receiving antenna of an interrogator at a distance of  $z = 20\lambda$ ; the microstrip element is configured such that  $L = 0.36\lambda$ ,  $w = 0.0525\lambda$ ,  $h = 0.02\lambda$ , and five elements are spacing of  $0.5\lambda$ , and this figure shows results by changing combinations of modulation phases of each element; Phase XXXXX in the graph (where X is 0 or 1) represents a modulation phase of each element and a phase difference of  $180^\circ$  is present between 0 and 1; this graph shows that high response sensitivity can be obtained in a wide range by sequentially changing modulation phases of each element;

FIG. 29 is an example program of FORTRAN for estimating the three-dimensional location of an RFID

tag;

FIG. 30 is an example program of FORTRAN for estimating the three-dimensional location of an RFID tag;

5 FIG. 31 is an example program of FORTRAN for estimating the three-dimensional location of an RFID tag; and

FIG. 32 is an execution example of a FORTRAN program for estimating the three-dimensional location of an RFID tag.  
10

#### EXPLANATIONS OF LETTERS OR NUMERALS

[0027]

1 one of two elements of a conventional dipole  
15 antenna for RFID.

2 the other one of two elements of the conventional dipole antenna for RFID.

3 one of two element strip conductor of a divided microstrip antenna for RFID according to an example of  
20 the present invention.

4 the other one of two element strip conductor of the divided microstrip antenna for RFID according to an example of the present invention.

5 GND plate of the divided microstrip antenna for  
25 RFID according to an example of the present invention.

(1) feeding point of the conventional dipole antenna for RFID.



(2) another feeding point of the conventional dipole antenna for RFID.

(3) feeding point of the divided microstrip antenna for RFID according to an example of the present invention.

(4) dividing position of the divided microstrip antenna for RFID according to an example of the present invention.

(5) GND point of the divided microstrip antenna for RFID according to an example of the present invention.

c1201 In the case of single reading (packets cannot be multiplexed at the same time), semi-synchronous delay detection is performed.

c1202 In the case of double reading (two packets can be multiplexed at the same time), carrier phase split synchronous detection is performed.

c1203 A received carrier is modulated and ID codes are transmitted in packets.

c1204  $t_{mn}$  is determined for each RFID by generating random numbers

c1401, c2401, c2601 A receiver signal level of  $f_0 + f_{L0}$  is read.

c2201 Synchronous detection of  $\omega_n + \Delta$  is performed for each antenna reception signal.

c2202 A three-dimensional location is estimated based on at least three parameters; in practice, a reflected wave is present, and therefore time-delay

measurements are performed using the MUSIC algorithm based on differences between multi-frequency response phases.

c2801 1 and 0 represent a phase difference of  $180^\circ$ .

5 c2802 High sensitivity is realized in a wide range by successively switching between modulation phases.

c2803 Modulation phase of each element

D1, D2, D3, D4, D5, D6 Schottky-barrier diode

D7, D8 PIN diode

10 D9 Zener diode

#### BEST MODES FOR CARRYING OUT THE INVENTION

[0028] An embodiment of the present invention will now be described.

15 In the present invention, the dividing position of a divided microstrip antenna is slightly deviated from the longitudinal center point across strip conductors.

Now, assuming that the center point lies at the 50% position with respect to the length of the strip  
20 conductor, the dividing position is preferably 55% to 80%.

[0029] When the dividing position is 55%, the modulation efficiency (the level of a reply signal) is maximized. However, the resistive part of a variable impedance  
25 element exerts the influence which is important to the efficiency of receiving power.

Also, when the dividing position is 80%, the resistive

part of a variable impedance element doesn't influence to the efficiency of receiving power too much, though the modulation efficiency is decreased.

[0030] Thus, it is preferred that, when the resistance of the variable impedance element is small, the dividing position is approximately 55%, and when the resistance of the variable impedance element is relatively large, the dividing position is considerably further deviated from the center.

10 [0031] (Example 1)

FIG. 3 illustrates the basic configuration of an RFID tag device of the present invention. In this figure, the antenna of the RFID tag device includes a ground plane conductor, an insulating layer and a divided strip conductor. The RFID tag device shown in this figure is for use in the 2.45 GHz band, and all specified dimensions are in units of mm. Also, the dividing point of the divided strip conductor is deviated slightly more than equal division in the longitudinal direction, and this feature achieves the effect of improving the reception efficiency of the antenna.

[0032] FIG. 4 illustrates the details of the control circuit chip shown in FIG. 3 and connections between the divided strip conductor and the control circuit.

25 [0033] In FIG. 4, the control circuit chip and the antenna are connected at six points A, B, C, D, E and F. PIN diodes D7 and D8 for impedance modulation are

connected between A and B and between D and E,  
respectively, and a feeding point of the antenna lies  
between C and F. Here, the point C is slightly deviated  
from the center point of the strip conductor width, and  
5 this feature achieves the effect of improving the  
reception efficiency of the antenna. Also, the point F  
is connected to the ground plane conductor via a  
through-hole. The terminals C, E and F constitute the  
three terminals of the three-terminal circuit.

10 [0034] The operation principle of the power supply  
circuit in FIG. 4 is shown in FIG. 5. FIG. 5(a) is a  
boost rectifier circuit called "Cockcroft-Walton  
circuit", in which a plurality of rectifier diodes and  
capacitors are connected in a ladder configuration, so  
15 that a sine wave signal with an amplitude of  $V_i$  can be  
output after being rectified to a DC voltage of  $K(V_i - l_j)$   
greater than  $V_i$  [ $K$  is the number of ladder steps;  $l_j$  is a  
forward drop voltage of a diode]. However, as shown in  
FIGS. 10 and 11, this circuit has a drawback in that  
20 when it is used in a high frequency band (e.g., 2.45  
GHz), the junction capacitance of each diode becomes  
input load and therefore input impedance becomes  
extremely low, which lowers the output voltage.

[0035] FIG. 5(b) is an operational principle diagram of  
25 the boost rectifier circuit of the present invention. An  
 $N\lambda_g/4$  short stub ( $\lambda_g$  is an effective wavelength of the  
transmission path;  $N$  is an odd number being 1 or 3)

exhibits an equivalent impedance of an inductance having a high Q-value in a high frequency range with respect to an input signal in the vicinity of  $\lambda_g$ . Even if a ladder boost section of FIG. 5(b) is a capacitive load, an  
5 inductive impedance can be maintained by a parallel resonance operation. On the other hand, in a tank circuit boost section of FIG. 5(b), the inductive impedance and a capacitive feed impedance generate an RF signal, which has a large amplitude of  $V_L = V_i / (R_L \cdot W_o)$   
10  $\gg V_i$ , between G and F by a series resonance operation, so that the circuit of FIG. 5(b) can obtain a DC output voltage of  $20V_i$  or more.

[0036] FIG. 17 is a behavioral analysis result of the boost rectifier circuit of the present invention, from  
15 which it is appreciated how an input voltage of  $50\Omega / -10$  dBm ( $0.07 V_{rms}$ ) is boosted and rectified to 1 V or more at 2.45 GHz.

[0037] Next, the control circuit chip of FIG. 4 is described in detail.

20 [0038] When  $V_{DD}$  is applied, an oscillator circuit generates a clock signal of  $f_s$ . When  $V_{DD}$  and the clock signal are applied, an output timing circuit generates a timing signal (an output enable signal) for anticollision as shown in FIGS. 12 and 13. When the  
25 output enable signal and the clock signal are applied, an address counter outputs memory read addresses one after another for each clock "L" pulse. Note that the

data transmission rate in this case is  $2f_s / L$  (bit/sec). The memory sequentially outputs 2-bit information recorded at addresses designated by the address counter. A 1/4 frequency divider outputs a signal corresponding to 1/4 of  $f_s$ . A shift register operates in accordance with the clock  $f_s$ , and phase-shifts the output of the 1/4 frequency divider in units of  $90^\circ$ . When the output enable signal is applied, a data selector selects and outputs one of four phase outputs ( $0^\circ$  to  $270^\circ$ ) of the shift register in accordance with a 2-bit memory output. [0039] However, it is possible to apply MPSK modulation by using a 1/M frequency divider, an M-stage shift register and an M-input data selector. In this case, it is possible to achieve the effect of increasing the amount of information that is transmitted per unit transmission power.

[0040] The output of the data selector changes the amplitude of current flowing through resistances to the PIN diodes D7 and D8 with a cycle of  $f_s / 4$ , thereby modulating a connection impedance between the divided strip conductors. As shown in FIG. 14, the change of the impedance changes a mutual coupling impedance between an antenna of an interrogator and the antenna of the RFID tag, so that a reflection coefficient  $\Gamma$  of the antenna of the interrogator is changed with a cycle of  $f_s / 4$ . FIG. 15 is an example of a signal measured with a spectrum analyzer. That is, from which it is possible to

identify signal components ( $f_0 + f_{LO}$ ,  $f_0 + 3f_{LO}$ , etc.), which are generated as a result of an incident wave of  $f_0$  having been modulated by the change of  $\Gamma$  with a cycle of  $f_{LO}$ . In this case,  $f_{LO} = f_s / 4$ , and because the

5 interrogator can accurately determine  $f_0$ , it is possible to readily evaluate the oscillating frequency  $f_s$  of the oscillator circuit at the tag based on the measured spectrum ( $f_0 + f_{LO}$ ,  $f_0 + 3f_{LO}$ , etc.). Specifically, by using, for example, a quartz resonator temperature

10 sensor as the oscillator circuit at the tag, it is also possible for the interrogator to monitor the ambient temperature at the point of the tag.

[0041] Incidentally, the microstrip antenna used for the RFID tag device of the present invention is explained

15 with respect to its property. The microstrip antenna is configured simply by providing a ground plane close to a plate-like dipole antenna, and therefore might be considered as if it is an antenna that behaves as a dipole, but in fact, its behavioral principle is

20 considerably different from that of the dipole antenna. Specifically, the dipole antenna is an electric current antenna, and the microstrip antenna is a magnetic current antenna. The reason why in the present invention, two PIN diodes for impedance modulation are provided at

25 opposite ends of the strip conductors in the width direction is that electric current flowing through the strip conductors is concentrated at the opposite ends in

the width direction.

[0042] FIG. 16 is an example of analyzing the level of a response signal that can be received by an interrogator by using antenna length  $L$  as a parameter in the evaluation system of FIG. 14, with respect to the case where a conventional dipole antenna having no ground plate is used in an RFID tag and the case where the divided microstrip antenna of the present invention is used in an RFID tag. As can be seen from this figure, the method of the present invention is capable of receiving the response signal with a level greater by about 10 dB (10 times greater power) compared to the conventional method.

[0043] FIGS. 18 through 20 show changes in frequency at response receiver levels in the evaluation system of FIG. 14 with respect to design parameters  $w$  and  $h$  of the microstrip antenna (it is assumed that  $L = 0.36 \lambda$  is fixed). It can be appreciated from FIG. 18 that by reducing  $h$  (the thickness of an insulator), it is possible to make adaptation to lower frequencies with the same size (size reduction with the same frequency), but an available frequency bandwidth becomes narrow.

[0044] Also, it can be appreciated from FIG. 19 that by increasing  $w$  (the strip conductor width), it is possible to make adaptation to lower frequencies with the same size, but an available frequency bandwidth becomes narrow.



[0045] FIG. 20 is a result of analyzing influences of a series resistance in PIN diodes for impedance modulation that are exerted on the receiver level with respect to the cases of making adaptation to lower and higher frequencies with the same size. As can be seen from this figure, in the case of size reduction with the same frequency (reduction in  $h$ , increase in  $w$ ), considerable influences are exerted by the series resistance of the PIN diodes, and therefore it is necessary to reduce the resistance in order to obtain a high response receiver level. In order to allow the PIN diodes to operate with low resistance, there is no choice but to apply a large current or increase junction capacitance (large area, short junction). The large current increases power consumption of the RFID tag device, and therefore is undesirable.

[0046] FIG. 21 is a result of analyzing a maximum response receiver level in the evaluation system of FIG. 14 by using the series resistance and junction capacitance of the PIN diodes as parameters. As can be seen from this figure, the response receiver level does not change substantially when the junction capacitance of the PIN diodes is increased, and therefore it is possible to obtain a high response receiver level even by using relatively low-cost PIN diodes.

[0047] Also, instead of the PIN diodes, it is possible to use varactor diodes, and transistors such as MOSFET may

also be used. In such a case, it is possible to further reduce the power consumption.

[0048] Also, when considering longitudinal connections of capacitors in a ladder boost rectifier circuit of a power receiving circuit as GND- and receiving-side rails, it is possible to consider diodes as rungs that join them. Capacitances of all the capacitors are normally equalized to maximize the booster efficiency, but in the present invention, the capacitor capacitance of the receiving-side rail is made smaller by one digit compared to that of the GND-side rail (specifically, GND-side rail: receiving-side rail = 1 : 0.05), and the first diode (between the GND and the receiving point) is eliminated, whereby it is possible to reduce input load capacity and receive a high-frequency and high-impedance input with a DC short.

[0049] (Example 2)

(A method for detecting the position of a moving object without an RFID tag)

20 The feature of the RFID tag of the present invention that is capable of relatively long range communication in spite of having no power supply is utilized.

[0050] Assuming that the positions of tags #1 through #4 and interrogators #1 and #2 are known as shown in FIG. 6, it is possible to estimate the position of a mobile object based on information concerning paths obstructed by the moving object.

[0051] In this case, a system may be configured such that  $f_{m1} = f_{m2}$ ,  $f_{s1} = f_{s2} = f_{s3} = f_{s4}$ , the interrogators provide CW outputs in a time-division system, and the tags respond by an anticollision method.

5 [0052] Further, a system may be configured such that  $f_{m1} \neq f_{m2}$ ,  $f_{s1} = f_{s2} = f_{s3} = f_{s4}$ , the interrogators successively provide CW outputs, and the tags respond by an anticollision method.

[0053] Furthermore, a system may be configured such that  
10  $f_{m1} \neq f_{m2}$ ,  $f_{s1}$ ,  $f_{s2}$ ,  $f_{s3}$  and  $f_{s4}$  are all different frequencies, and the interrogators successively provide CW outputs.

[0054] (Example 3)

(A method for detecting the position of a moving  
15 object with RFID)

The feature of the RFID tag of the present invention that is capable of relatively long range communication in spite of having no power supply is utilized.

[0055] As shown in FIGS. 22 and 23, a plurality of  
20 receiving antennas are used at the master device, and CW signals are transmitted at two or more frequencies to detect differences in phase between response signals from RFID tags, making it possible to estimate three-dimensional locations of the RFID tags.

25 [0056] FIG. 7 illustrates the configuration of a master device. A Fourier transform section performs time-series Fourier integration on Re and Im data of antennas #1

through #4 to calculate a spectrum phase at a frequency  $\Delta$ . In this case, it is assumed that phase differences due to each antenna cable and down converter and a time delay in operations of a selecting switch are calibrated  
5 for the compensation.

[0057] Note that FIGS. 29 to 31 present an example of an algorithm implemented in FORTRAN language for estimating three-dimensional locations of RFID tags in the configuration of FIG. 7, and FIG. 30 is an example of  
10 the program. Also, the analysis of RMS error in estimation of three-dimensional locations of the RFID tags in FIG. 23 is a result of computer simulation by the program of FIGS. 29 to 31 using the number of receiving antennas and error in distance measurement as  
15 parameters.

Note that in the program shown in FIGS. 29 to 31, the simulation for estimating the three-dimensional locations of the RFID tags is carried out in the following procedure.

20 (1) Assuming that radio wave frequencies output from interrogators are  $f_1 = 2.000$  GHz,  $f_2 = 2.025$  GHz and  $f_0 = 2(f_2 - f_1) = 0.05$  GHz and  $\lambda_0 = 15$  cm, the delay evaluation cycle length is taken as  $dlh = \lambda_0 / f_0$  (cm) and the number of receiving antennas is taken as  $na = 16$ .

25 (2) The three-dimensional locations of the RFID tags are entered.

(3) Distances  $D$  are obtained based on phases at which

response signals from the RFIDs are received by receiving antennas. In this case, spacing between the receiving antennas are taken as 50 cm.

$$D = \{ \text{Phase} (f_2) - \text{Phase} (f_1) \} \times 3 \times 10^{10} / \pi f_0 \text{ (cm)}$$

5 (4) Noise is added to the distances D obtained based on the phases of reception by the receiving antennas, and differences in distance to a reference antenna are calculated. Here, in common with all the distances D obtained at the above step (3), offsets such as  
10 distances  $D_x$  from transmitting antennas of interrogators to the RFID tags and differences in response phase of the RFID tags are included, and therefore the reason why the differences to the reference antenna are calculated is to achieve the effect of eliminating influences of  $D_x$   
15 and so on.

(5) The differences in distance between the receiving antennas are compensated for the delay evaluation cycle length  $d_{lh}$ .

(6) Three-dimensional locations  $X_P$ ,  $Y_P$ ,  $Z_P$  of the RFID  
20 tags are assumed.

(7) Distances to the assumed tag locations  $X_P$ ,  $Y_P$ ,  $Z_P$  are obtained based on the phases of reception by the receiving antennas.

(8) The differences in distance between the antennas,  
25 which are actually received at the above step (5), are compared with differences between the distances to the assumed tag locations that are obtained at the above

step (7) based on the phases of reception by the receiving antennas.

(9) The distance differences compared above are compensated for the delay evaluation cycle length  $dlh$ .

5 (10) Error energies are obtained with respect to the compared distance differences between the receiving antennas that have been subjected to the above cycle compensation.

(11) After repeating the processes of the above steps  
10 (6) through (10), three-dimensional locations of five positions of the tag are listed in ascending order of error energy.

(12) Approximate results for estimating the three-dimensional locations of the listed five positions of  
15 the tag and the error RMS values are displayed.

(13) An assumed tag location that provides a minimum error energy is obtained in three dimensions by repeating the above processes in (6) through (10) with more fragmented steps focusing on each of the three-  
20 dimensional locations of the listed five positions of the tag.

(14) The three-dimensional assumed tag location that provides the minimum error energy is displayed as a finally estimated RFID tag location.

25 [0058] (Example 4)

(A method for longer-range communication with RFID tags)

The RFID tag of the present invention, even by itself, can perform communication within a relatively long range of about 10 m. However, if it is used for a sign on an expressway and so on, the communication range of about 5 10 m is highly unlikely to be sufficient. Accordingly, RFID tags of the present invention are arranged in an array to add a phase difference to a response signal from each tag, so that the response signal can be returned with high sensitivity to interrogators in a 10 wide area, thereby making it possible to perform communication within a range of about 100 m. An example thereof is shown in FIGS. 24 through 28.

[0059] The method described herein controls directionality by the arrangement of the RFID tags and 15 combinations of response signal phases at  $0^\circ/180^\circ$  for each tag; however, it is also possible to more strictly control the directionality by assigning more fragmented phase differences as shown in FIG. 8.

[0060] Note that the combinations of phases at  $0^\circ/180^\circ$  in 20 FIG. 24 through 28 can be readily realized by using an ExOR as shown in FIG. 9.

Also, it is made possible to communicate with interrogators in a wide area by periodically changing the combinations of phases provided herein to perform 25 scanning with a beam of intense response radio waves that can be returned only within a narrow area.

## INDUSTRIAL APPLICABILITY

[0061] Common features of being inexpensive, having no power supply, requiring no maintenance and being capable of long range communication (up to about 100 m) are used  
5 as the means of implementation.

[0062] (1) Because of the ease of attachment to a road sign, etc., and the fact that information can be read by an interrogator from relatively afar and, if radio wave diffraction is utilized, even from a position behind  
10 another vehicle, it is possible to construct an intelligent navigation system notifying information concerning the speed limit, indication of a curve/fork, etc., to the driver and an automatic operation or safety support device of the vehicle.

[0063] (2) Because of the ease of attachment to an advertisement material such as a poster and the fact that information can be read by an interrogator from relatively afar, it is possible to realize an applied device for reading an Internet home page address on a  
20 posted advertisement from a distance and construct a product advertising system. In this case, it is conceivable to simultaneously read a plurality of posters having the same address or simultaneously read a plurality of posters having a different address. A  
25 reader (an interrogator) owned by the user incorporates, as a part of ID, a code that represents a color corresponding to visual information of a poster or



attached tag or a relatively simple symbol/mark to facilitate selection of an Internet link, avoid displaying identical addresses and present displays in order of address hierarchy.

5 [0064] (3) Because of the ease of attachment to a sample or product such as an exhibit and the fact that information can be read from relatively afar, it is possible to construct a reservation and market research system that, without necessitating approaching the  
10 exhibit, transmits a product reservation and information added with preferences regarding the size and color to the seller of the product (a reader is additionally provided with a wireless LAN function or a cell phone function, or the reader accumulates information and  
15 returns it to the seller). In this case, it is conceivable to simultaneously read information concerning a plurality of products having the same ID from a display shelf or a showcase or simultaneously read a plurality of pieces of information concerning  
20 products having a different ID. The reader owned by the user incorporates, as a part of ID, a code that represents a color corresponding to visual information of a product or attached tag or a relatively simple symbol/mark to facilitate selection of a preferred  
25 product, avoid displaying identical ID codes or symbols and provide displays in order of ID code hierarchy.

[0065] (4) Because of easy incorporation into cars, home

appliances, etc., and the feasibility of being read from relatively afar, it is possible to construct a system for performing classification for recycling or deterring illegal waste dumping, stealing for resale, etc.

5 Specifically, by recording, together with an ID code, not only information at the time of production but also information concerning the owner or information concerning the presence or absence of hazardous substances, it is made possible to allow a relatively  
10 simple reader to perform concurrent identification from afar.

[0066] (5) According to the RFID tag device of the present invention, not only information recorded in a memory but also information regarding a selected voting  
15 switch or the like can be returned as a response signal and readily read from relatively afar, and therefore it is possible to construct an instant voting/ballot counting system at an event site or the like. The RFID tag of the present invention has no power supply and a  
20 thin and relatively simple structure, and therefore the cost for mass production is conceivably about several tens of yen. Accordingly, it can be left uncollected after used as an invitation or ticket for an event, or it can be collected and repeatedly used.

25 [0067] (6) According to the RFID tag of the present invention, not only information recorded in a memory but also information measured by various transducers can be

returned as a response signal and read from relatively  
afar, and therefore it is possible to construct a system  
that uses a relatively small number of interrogators to  
continuously monitor physical condition information such  
5 as an ill-conditioned person's heartbeat from afar  
without imposing a burden on that person.

[0068] (7) According to the RFID tag of the present  
invention, not only information recorded in a memory but  
also information measured by various transducers can be  
10 returned as a response signal and read from relatively  
afar, and therefore it is possible to construct a system  
that continuously monitors a device, such as high-  
voltage power transmission and distribution equipment,  
which is difficult to connect to a sensor and cannot be  
15 readily suspended for maintenance because it is  
dangerous to gain access thereto.

[0069] (8) In the example of FIG. 4, the stub resonance  
boost rectifier circuit and the control circuit in FIG.  
2 illustrating the configuration of the RFID tag device  
20 of the present invention are integrated as a control  
circuit chip. However, a highly-versatile, low power  
consumption microprocessor (e.g., PIC16F684 manufactured  
by Microchip Technology Inc.) can be used as the control  
circuit and combined with the stub resonance boost  
25 rectifier circuit. By configuring as such, it is made  
possible to input analog data or digital data, so that  
such data can be temporarily stored in the RFID tag or

can be stored in an EEPROM for a long period of time.  
Further, it can be used for remote control reception  
with a home appliance or the like, but also it is  
possible to read a variety of types of information with  
5 no power being supplied. For example, with a reader (a  
remote controller), it is possible to check information  
such as:

- Power is not being supplied;
- xxx is out of order;
- 10 • yyy is still inside xxx;
- yyy is reserved for xxx;
- yyy was last used on x month, x day at x o'clock,  
x minutes.

[0070] (9) The RFID tag device of the present invention  
15 can be operated to the same standard as a 2.45 GHz  
wireless LAN, and therefore it is possible to use, as an  
interrogator, a wireless LAN base station or a wireless  
LAN terminal. In this case, a 2.45 GHz carrier signal  
needs to be transmitted from the wireless LAN to provide  
20 operating power for the RFID tag device, but it may be a  
radio wave of an FHSS or OFDM scheme, which is a  
wireless LAN standard. The RFID tag device returns reply  
information on a subcarrier signal offset by an  
oscillating frequency of a local transmitter in the tag,  
25 and therefore the reply information from the RFID tag  
can be read at the wireless LAN by demodulating a  
subcarrier signal synchronously detected with a

transmission carrier.